Southeastern Geology: Volume 6, No. 4
September 1965

Editor in Chief: S. Duncan Heron, Jr.

Abstract

Academic journal published quarterly by the Department of Geology, Duke University.

J. R. Butler

SOUTHEASTERN GEOLOGY

PUBLISHED AT DUKE UNIVERSITY DURHAM, NORTH CAROLINA

VOL. 6 NO. 4 SEPTEMBER, 1965

SOUTHEASTERN GEOLOGY

PUBLISHED QUARTERLY

AT

DUKE UNIVERSITY

This journal welcomes original papers on all phases of geology, geophysics, and geochemistry as related to the Southeast. Transmit manuscripts to S. DUNCAN HERON, JR., BOX 6665, COLLEGE STATION, DURHAM, NORTH CAROLINA. Please observe the following:

(1) Type the manuscript with double space lines and submit in duplicate.
(2) Cite references and prepare bibliographic lists in accordance with the method found within the pages of this journal.
(3) Submit line drawings and complex tables as finished copy.
(4) Make certain that all photographs are sharp, clear, and of good contrast.
(5) Stratigraphic terminology should abide by the Code of Stratigraphic Nomenclature (AAPG, v. 45, 1961).

Proofs will not be sent authors unless a request to this effect accompanies the manuscript.

Reprints must be ordered prior to publication. Prices are available upon request.

* * * * *

Subscriptions to Southeastern Geology are $5.00 per volume. Inquiries should be addressed to WM. J. FURBISH, BUSINESS AND CIRCULATION MANAGER, BOX 6665, COLLEGE STATION, DURHAM, NORTH CAROLINA. Make check payable to Southeastern Geology.

SOUTHEASTERN GEOLOGY

Table of Contents

Vol. 6, No. 4

1965

FREQUENCIES OF INFAUNAL INVERTEBRATES RELATED TO WATER CONTENT OF CHESAPEAKE BAY SEDIMENTS

by

W. Harrison

Environmental Science Services Administration

U. S. Coast and Geodetic Survey[1] and

Virginia Institute of Marine Science[2]

and

Marvin L. Wass

Virginia Institute of Marine Science

ABSTRACT

The following relationship was investigated for a total of 44 stations, using sequential (linear) multiregression analysis:

$$A = f(D, S_a, S_i, C, M_z, S_o, W)$$

where A = the frequency of an infaunal invertebrate species, D = water depth at the station, S_a = per cent sand, S_i = per cent silt, C = per cent clay, M_z = mean grain size, S_o = sediment Sorting Coefficient, and W = water content. Three animals were chosen for the dependent variable: Ensis directus, Nephtys incisa, and Retusa canaliculata.

Results of the least-squares search procedure indicate that if the water content is carefully determined this variable always appears as one of the most important, when the independent variables are considered in combinations of two or three at a time. The implication is that water content, a mass property of the sediment that reflects the interrelationships of mean grain size, sorting, grain packing, and mineralogy, is a highly useful environmental variable that should be measured in studies that attempt to establish animal-sediment relationships.

---

1. Contribution No. 2, Land And Sea Interaction Laboratory, 439 York Street, Norfolk, Virginia 23510.

2. Contribution No. 186, Virginia Institute of Marine Science, Gloucester Point, Virginia 23062. This investigation was supported in part by U. S. Army Corps of Engineers Contract No. DA-44-110-CIVENG-61-181.

INTRODUCTION

During the period June 7-10, 1962, open-barrel cores were taken with a 57-kg gravity corer at 44 stations in lower Chesapeake Bay (Fig. 1). Samples of benthic fauna were also taken, by using a $1/15\ m^2$ Petersen dredge, followed by screening through a 1-mm sieve. The following seven environmental variables were estimated according to procedures outlined elsewhere (Harrison, Lynch, and Altschaeffl, 1964): water depth, per cent sand, per cent silt, per cent clay, mean grain size, sediment sorting, and gross water content. The descriptive properties of the sediments were determined from subsamples of the top 0.2 m of each core, while water-content was determined on the whole core. The average core length was 0.43 m, while the longest core had a (corrected) length of 0.9 m. Water-content values of 16 of the 44 cores taken were corrected for core shortening. (Grease smeared on the outside of the corer permitted an estimate of the true depth of penetration and the determination of true core length prior to shortening). Although it would have been best if the water-content were measured in the uppermost few centimeters, in practice it is very difficult to obtain precise values in this zone. It was felt, moreover, that a reasonable approximation of near-surface water-content could be obtained from measurements on the whole cores.

Mean grain size was determined as

$$M_z = \frac{\phi 5 + \phi 16 + 4\,\phi 50 + 2\,\phi 84 + \phi 95}{10}$$

and the Sorting Coefficient as

$$S_o = \frac{\phi 84 - \phi 16}{4} + \frac{\phi 95 - \phi 5}{6.6}$$

where phi (ϕ) is the $\log_2$ transformation from millimeters (arithmetic interval) to phi units (geometric interval). Data for the 44 stations are given in Table 1.

Acknowledgments

The authors are indebted to Dr. William J. Clench, of the Museum of Comparative Zoology, Harvard University, for the identification of representative specimens of Ensis.

DATA ANALYSIS

Several methods are available for analyzing observational data that involve interrelationships among independent variables. The method chosen was that of sequential multiregression analysis, and a complete explanation of the technique with several worked examples is given by Harrison and Krumbein (1964), and Krumbein, Benson, and

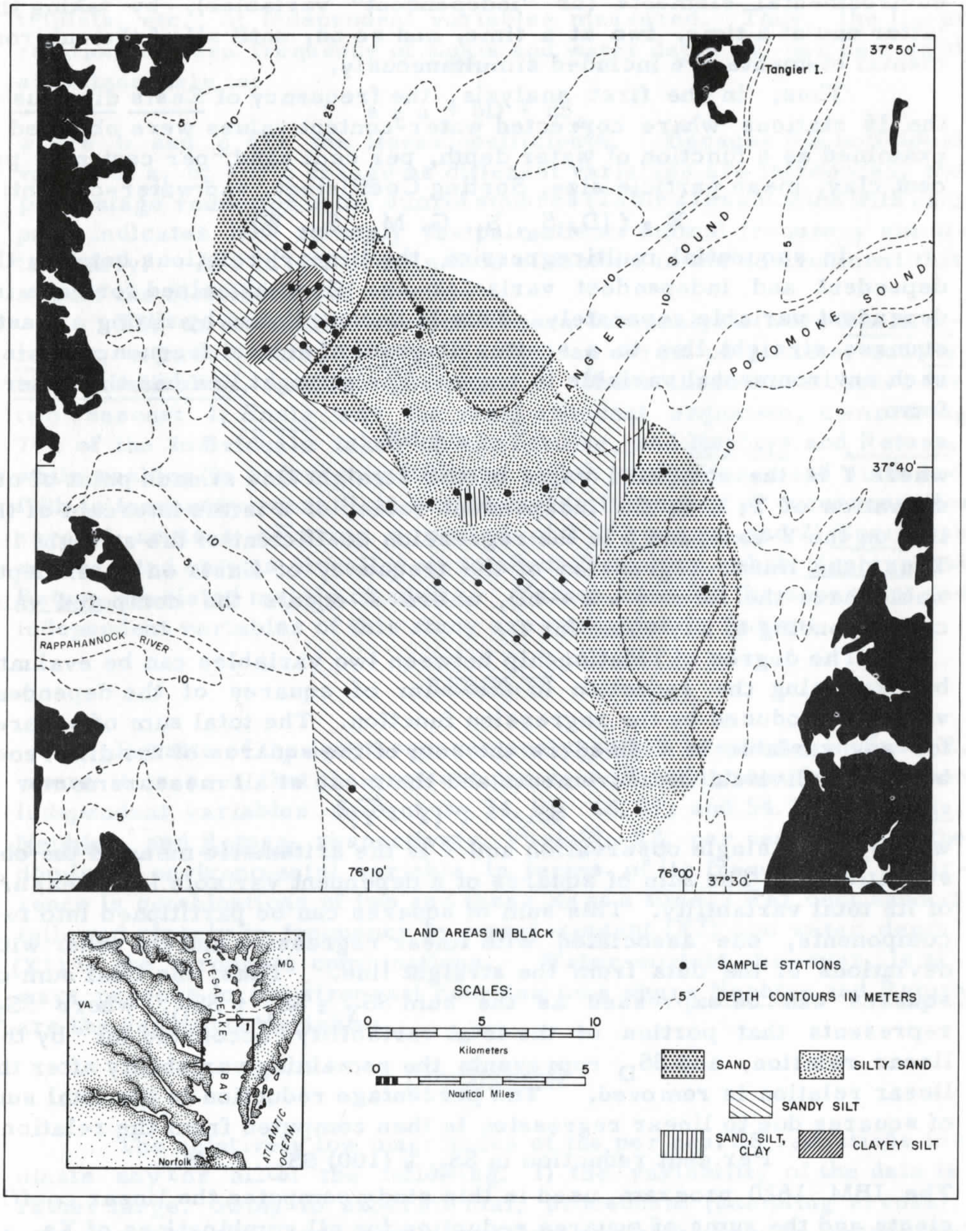

Figure 1. Map of area of investigation, showing sample stations, general bathymetry, and distribution of bottom sediments. Sediment-type designations after Shepard (1954, p. 157).

Hempkins (1964). The technique involves the measure of the relationship of a given dependent variable in terms of several controlling environmental elements (or "independent" variables), by taking the latter one at a time, two at a time, and so on, until all of the environmental elements are included simultaneously.

Thus, in the first analysis, the frequency of Ensis directus at the 16 stations where corrected water-content values were obtained is examined as a function of water depth, per cent sand, per cent silt, per cent clay, mean particle size, Sorting Coefficient, and water-content:

$$E = f(D, S_a, S_i, C, M_z, S_o, W).$$

In sequential multiregression the (linear) relations between the dependent and independent variables are first examined for each independent variable separately. This is accomplished by fitting a least-squares straight line to a scatter diagram of animal frequency against each environmental variable in turn. The straight line has the general form

$$\hat{Y} = a + bX$$

where $\hat{Y}$ is the computed value of the straight line at each point of observation of Y; X is the independent variable; a is the intercept of the line on the Y-axis; and b is the regression coefficient of the straight line. Thus, the linear regression of the frequency of Ensis on water depth would have the form $\hat{s} = a + bD$, where $\hat{s}$ equals the computed value corresponding to any value for D.

The degree of relationship between two variables can be evaluated by examining the reduction in the sum of squares of the dependent variable produced by the regression function. The total sum of squares for any variable is defined as the sum of the squares of the difference between individual measurements and the mean of all measurements:

$$SS_Y = \Sigma (Y - \overline{Y})^2$$

where Y is a single observation and $\overline{Y}$ is the arithmetic mean of the observations. The sum of squares of a dependent variable is a measure of its total variability. This sum of squares can be partitioned into two components, one associated with linear regression and the other with deviations of the data from the straight line. Thus, the total sum of squares can be expressed as the sum $SS_Y = SS_L + SS_D$, where SS_L represents that portion of the total variability "accounted for" by the linear relation, and SS_D represents the remaining variability after the linear relation is removed. The percentage reduction in the total sum of squares due to linear regression is then computed from the relation

$$\text{Per cent reduction in } SS_X = (100)\, SS_L \;/\; SS_Y$$

The IBM 1620 program used in this study computes the linear coefficients and the sums of squares reduction for all combinations of Xs, as stated, and the output lists the Xs involved and the corresponding per-cent SS reductions.

Because of limitations on regression analysis with one independent variable at a time, sequential multiregression is used to estimate the simultaneous influence of two or more independent variables on the animal frequency. Sequential muitiregression treats the independent variables one at a time, two at a time, and so on for all possible pairs, triplets, etc., of independent variables measured. Thus, the linear relation between frequency of Ensis and water depth and per cent sand simultaneously is:

$$\hat{s} = a + bD + cS_a$$

where b and c are the linear coefficients. Because the individual values of a, b, and c change as different variables are introduced, the percentage reduction in the sum of squares (Table 2) associated with each pair indicates how strongly the pair affects animal frequency simultaneously. And it is a combination of factors in the environment that affects the distribution of species.

The three animal species chosen for analysis were Ensis directus, a razor clam, Nephtys incisa, an errant polychaete, and Retusa canaliculata, a minute gastropod. These three were chosen for two reasons: 1) Ensis was the most abundant organism, comprising 79% of the individuals taken on the cruise, and Nephtys and Retusa, while ranking (in order) only fifth and eighth in abundance and sixth and fifth in frequency, were first and second in frequency of occurrence for several cruises covering a period of 2 1/2 years, and 2) Ensis was represented only as juveniles up to about 2 cm long, while Nephtys and Retusa consisted mainly of adults. Values used for the dependent and independent variables of this study are presented in Table 1.

RESULTS

Results of the least-squares analyses are presented in Table 2, where it is seen that the greatest per cent SS reductions for all seven independent variables amount to 34.13, 48.57, and 54.29 for Ensis, Nephtys, and Retusa, respectively. Variable X2, per cent sand, is the dominant environmental variable in terms of its frequency of occurrence in combinations of two and three Xs at a time. Per cent sand is followed closely in frequency by water-content (X7) and water depth (X1) in the strongest combinations. Water-content, however, is always present in the strongest combinations where Nephtys and Retusa are the dependent variables.

DISCUSSION

The relatively low magnitudes of the per cent SS reductions indicate any or all of the following: 1) the variability of the data is rather large, owing to experimental, procedural (sampling errors), or natural factors; 2) additional important variables need to be included in the analysis; and 3) there is little true relationship between a dependent variable and one or more of the independent variables.

With regard to point 1, the so-called "noise content" of the data, it is seen that a clear difference exists between the total per cent SS reductions for N = 16 and N = 44, for both Nephtys and Retusa.

Table 2

The two strongest per cent reductions in animal-type sum of squares attributable to each of several combinations of seven environmental elements.

Animal	Environmental-element number combinations (X)[1]							Per cent reduction in SS	
Ensis directus (N=16)	1	2	3	4	5	6	7	33.75	All Xs
	1	2						32.42	Two Xs at
		2					7	31.82	a time
	1	2				6		33.42	Three Xs at
		2				6	7	33.22	a time
Ensis directus (N=44)	1	2	3	4	5	6	7a	34.13	All Xs
		2					7a	32.05	Two Xs at
	1	2						30.82	a time
		2				6	7a	33.44	Three Xs
	1	2				6		32.64	at a time
Nephtys incisa (N=16)	1	2	3	4	5	6	7a	48.57	All Xs
				4			7	35.60	Two Xs at
	1			4				33.94	a time
		2		4			7	38.29	Three Xs
			3	4			7	37.98	at a time
Nephtys incisa (N=44)	1	2	3	4	5	6	7a	14.73	All Xs
Retusa canaliculata (N=16)	1	2	3	4	5	6	7	54.29	All Xs
	1						7	39.38	Two Xs at
		2			5			36.02	a time
	1				5		7	51.47	Three Xs
	1	2			5			43.16	at a time
Retusa canaliculata (N=44)	1	2	3	4	5	6	7a	5.10	All Xs

[1] X1 = water depth, X2 = % sand, X3 = % silt, X4 = % clay, X5 = mean size, X6 = Sorting Coefficient, X7 = water content (corrected for core length), X7a = water content (mixed values, corrected and uncorrected for core length).

It will be recalled that the water-content data, where N = 16, are relatively noise free as far as analytical procedures are concerned. (This fact points up the need for using water-content values from open-barrel cores whose lengths have been corrected.) Sampling procedures may have introduced some noise, however, because at the 16 stations where water-content was carefully determined, cores[3] of various lengths were employed. It is quite likely that the noise content of the water-content variable would have been further reduced, had equal-length core samples been used, owing to the known relationship between water-content and depth in the sediment. (Calculations based on precision water-content determinations Harrison, Lynch, and Altschaeffl, 1964, Table 3 , on samples from piston cores taken in the area, show that the discrepancy between estimated and true water-content values for the surficial 5 cm of sediment is many times greater for calculations affected by the core-shortening process than for calculations obtained by assuming that the average water-content value for the whole core, whose length has been corrected, holds also in the 5 cm surface layer.)

The variability about the population mean of animal frequency, the dependent variable, would certainly have been reduced if replicate faunal samplings had been made and mean values used for the animal frequencies. Also to be considered in data reliability, where animals are involved, is the degree of maturity of the animals studied. This is illustrated by Ensis directus which occurs as adults in sandy areas of the lower Chesapeake. The number of eggs produced by an individual is probably quite large. Only one adult razor clam was taken in the area during the entire survey but more would surely have been collected by a sampling device penetrating to greater depths. The area sampled, however, is predominantly clayey and sandy silt with sand in the shoaler parts. The generally adverse nature of the bottom for this animal and the large numbers of juvenile Ensis, up to 39, 450/m^2 indicate a lack of ability to discriminate between substrates by larvae of this species. The results of the least-squares analysis support this assumption because there was so little difference in per cent-SS-reduction by all Xs (Table 2) between the samples run by differing methods of water-content analysis.

Point 2 above, the possibility that additional important variables need to be included in the analysis, will not be treated here, but it is believed that a more comprehensive study of this type should include measurement of such variables as salinity, pH, dissolved oxygen, and turbidity. Biological variables, such as the number of larvae passing a given station in one season or the frequencies of other

---

[3]See Harrison, Lynch, and Altschaeffl (1964, Table 2), cores 6, 7, 9, 10, 11, 12, 16, 19, 20, 21, 29, 31, 32, 34, 35, and 36.

Table 1

Values used for the dependent and independent variables in the least-squares analyses.

Station no.	Animal frequency (Ensis)	(Nephtys)	(Retusa)	Water Depth	% Sand	% Silt	% Clay	Phi mean size	Sorting Coeff.	Water cont. (%)
1	4	14	5	32	22	57	21	5.8	1.4	167
2	2	6	1	32	30	60	10	5.2	1.8	145
3	14	16	3	16	22	60	18	5.5	1.0	173*
4	12	16	5	28	27	56	17	5.9	2.1	296*
5	19	16	4	33	29	63	8	5.2	1.6	335*
6	14	13	5	14	19	49	33	6.0	2.3	255*
7	24	8	1	29	16	61	24	5.9	2.1	279*
8	115	19	3	30	19	60	21	5.8	2.2	263*
9	11	12	3	30	30	70	0	4.6	1.0	183
10	25	14	3	29	38	63	0	4.3	0.8	240*
11	670	31	9	31	62	28	10	3.9	2.1	50
12	582	0	6	9	100	0	0	2.5	0.5	62
13	0	11	13	5	21	65	14	5.6	1.9	181*
14	2	14	19	15	17	57	26	0.6	2.2	204*
15	41	17	11	18	19	71	11	5.5	1.7	216*
16	2630	2	10	18	82	12	7	2.9	1.9	34
17	121	26	23	14	46	47	7	4.3	1.8	109
18	100	12	5	27	80	14	6	3.1	1.9	40
19	76	14	0	19	68	22	10	3.7	2.0	73*
20	560	19	2	20	70	22	8	3.7	2.0	82*
21	217	21	2	14	29	64	7	0.5	1.6	145*
22	814	22	4	15	26	61	13	5.1	1.8	145*
23	2264	22	2	15	64	27	9	3.3	1.9	95*
24	192	29	0	13	40	59	1	4.6	1.4	130*
25	48	16	8	14	46	34	20	5.3	2.4	111
26	26	26	0	14	24	61	15	5.4	2.0	94
27	367	21	6	23	40	41	12	4.5	2.0	71
28	233	22	0	13	32	56	13	5.1	1.9	96
29	64	23	0	13	32	39	30	5.5	2.8	117
30	54	22	9	13	90	10	0	2.3	1.1	38
31	282	19	8	15	23	58	19	5.9	2.2	135
32	44	12	6	15	28	60	12	5.2	1.8	80
33	549	9	4	16	24	58	18	5.6	2.1	72
34	242	24	4	16	25	65	10	0.5	1.4	89
35	173	21	4	14	32	54	15	5.2	1.9	99
36	102	10	13	13	21	63	16	5.6	2.0	135
37	111	24	8	15	35	54	11	4.9	1.7	104
38	159	15	3	13	35	65	1	4.3	0.9	109
39	1861	11	0	16	85	11	4	2.6	1.5	44
40	1239	0	4	12	90	10	0	2.4	1.1	47
41	117	18	8	11	29	64	8	5.0	0.7	140
42	920	90	7	13	45	53	2	5.5	1.0	65
43	275	18	1	14	48	52	0	4.1	0.8	74
44	176	18	1	18	69	31	0	3.2	1.2	169

* As determined for corrected core length.

species in the sample, would be important additional independent variables for such an analysis.

Finally, with regard to point 3, the validity of the relationships noted between the animals and the environmental variables, the following can be noted. The reduction of the sum of squares is a measure of the mathematical association between variables, and is not necessarily the measure of a physical relationship. Where the independent variable has physical meaningfulness in the problem, however, it is not extreme to infer that the strength of the mathematical relation is also a measure of the strength of the physical relation. When the independent variables are taken several at a time, however, interrelations among the independent variables themselves may complicate interpretation of the sum of squares reduction. If a particular independent variable is itself dependent on some other variable, the apparent sum of squares reduction may in large part be influenced by such "hidden" relationships. That is to say, the particular independent variable in part repeats information associated with a more meaningful variable, and to that extent it is "redundant".

Redundant variables, that is, variables that in large part restate what some other variable has already measured, are common in early stages of quantification in the observational sciences, especially when physical models are not clearly discernible in the complex of observations. In these cases a method for "sorting out" a set of independent variables in terms of their importance or meaningfulness in controlling the response of some dependent variable, Y, helps to reduce the number of variables in the set to more manageable proportions. This process was conveniently accomplished in this study by the step-wise regression method.

Of the three variables (water depth, X1; per cent sand, X2; water-content, X3) that occur most frequently in the strongest combinations of Table 2, both per cent sand and water-content are redundant with water depth. As water depth increases the per cent sand decreases and sediment water-content increases. (Thus, water-content varies inversely with per cent sand.) Because of these redundant relationships, we may arbitrarily discard water depth and per cent sand in the final evaluation of the single most-significant environmental variable that occurs in combination with the others. It is perhaps not surprising that water-content, a "mass" property of the environment, is in fact (Table 2) the most significant of the environmental variables, when in combination. As a mass property it reflects the interrelationships of mean grain size, sorting, grain packing, grain mineralogy, and other factors.

Of the seven environmental variables considered, Sorting Coefficient was significant only in the three-variable analysis for <u>Ensis.</u> (Water-content and one of the sediment types were highest in per cent SS reduction.) Sediment type has often been shown to be of importance in distribution of infauna (Sanders 1958, 1960), but water-content apparently has not previously been considered in a subtidal area. However, Gee (1961) found a species of amphipod, Corophium arenarium, "more closely defined by water-content than by substratum composition" in an intertidal area. He further concluded that, "Where an area is fairly homogeneous with regard to substrate composition water-content becomes an important factor limiting distribution." The results of this study tend to bear out Gee's conclusion.

CONCLUSIONS

Limitations have been mentioned for the linear model used here in a least-squares search for significant combinations of independent variables found in a set of noisy and redundant data.

It seems clear, however, that while the investigator can make subjective judgments as to the environments preferred by organisms, careful determinations of the environmental variables, coupled with analytical techniques like the least-squares search procedure used here can more accurately suggest or delineate species requirements. The importance of water-content as a determinative environmental variable is suggested in this study by its repeated appearance (Table 2) as an influential independent variable when in combination with one or two of the other independent variables. It would seem wise to provide for careful measurement of this variable in future studies of animal-sediment relationships.

REFERENCES

Gee, J. M., 1961, Ecological studies in South Benfleet Creek with special reference to the amphipod genus Corophium: Essex Nat. 1961, p. 291-309.

Harrison, W., Lynch, M. P., and Altschaeffl, A. G., 1964, Sediments of lower Chesapeake Bay, with emphasis on mass properties: J. Sed. Petrology, v. 34, p. 727-755.

Harrison, W., and Krumbein, W. C., 1964, Interactions of the beach-ocean-atmosphere system at Virginia Beach, Va.: U. S. Army Coastal Eng. Res. Center Tec. Memo. 7, p. 1-102.

Krumbein, W. C., Benson, B., and Hempkins, W. B., 1964, Whirlpool, a computer program for "sorting out" independent variables by sequential multiple linear regression: ONR Tech. Rept., Cont. NONR-1228 (26), ONR Task No. 389-135, Northwestern Univ., Dept. of Geology, Tech. Rept. No. 14, p. 1-49.

Sanders, H. L., 1958, Benthic studies in Buzzards Bay: I. Animal-sediment relationships: Limnol. Oceanog., v. 3, p. 245-258.

__________, 1960, Benthic studies in Buzzards Bay III. The structure of the soft-bottom community: Limnol. Oceanog., v. 5, p. 138-153.

Shepard, F. P., 1954, Nomenclature based on sand-silt-clay ratios: Jour. Sed. Petrol., v. 24, p. 151-158.

LAUMONTITE-LEONHARDITE

from

DURHAM COUNTY, N. C.

by

Wm. J. Furbish
Duke University

ABSTRACT

Two differing occurrences of laumontite are discussed relative to their origin in either basic igneous rock or under incipiently metamorphic conditions. The weathering process and clay product, when a high calcium and magnesium and low potassium concentration exists in the weathering solutions, are considered. Physical properties of cleavage and fracture are shown to be partially dependent upon dehydration and possibly also on the variation of composition. The DTA pattern of material from one of the occurrences of laumontite is compared with parallel static X-ray diffraction results. It is also compared with Koizumi's dehydration curve for laumontite with a high degree of correlation occurring.

INTRODUCTION

When the calcium zeolite laumontite $Ca(Al_2Si_4O_{12}) \cdot 4H_2O$ is exposed to surface weathering conditions it may undergo dehydration and lose part of its water content to form the mineral phase leonhardite $Ca(Al_2Si_4O_{12}) \cdot 3\ 1/2\ H_2O$. This process is a reversable dehydration reaction under normal atmospheric conditions (Des Cloizeaux, 1862) and is accompanied by a change in intercleavage angles, axial ratio and optical properties. These changes have been thoroughly documented and discussed by Coombs (1952). Both phases of the mineral are discussed in this work and the necessary name will be used where appropriate.

Various types of occurrences and associations of laumontite have been described in the literature and the more pertinent are summarized by Deer et. al. (1963). They are formed by replacement of tuffs, through breakdown of feldspar under incipient metamorphic conditions, in veins and vesicles of igneous rocks, and as an authigenic mineral in sedimentary rocks.

In this paper material from two types of occurrences in the Durham, N.C. area will be discussed, with special reference to weathered end products, physical properties and the author's interpretation of the leonhardite DTA pattern.

Acknowledgment

The author wishes to express his appreciation to S. B. Weed for assistance with the DTA study and to H. S. Brown for many helpful suggestions and review of the manuscript.

GEOLOGIC OCCURRENCE

Laumontite Associated with Diabase Dikes

The first type of laumontite occurrence is found in and is associated with Triassic age diabase dikes and irregular bodies that are intrusive into the Triassic age sediments of the Durham Sub-basin of the Deep River Triassic Basin of North Carolina. Hermes (1964) has discussed the petrology of these intrusive bodies. He has shown that the mineral proportions are highly variable from one body to another and within any single body, with the olivine content ranging from 0% to 54%. The main primary mineral constituents of these igneous bodies are plagioclase (average An_{64}), augite, and olvine in order of their decreasing abundance. The occurrence of laumontite in such basic igneous rocks is not unusual and has been noted previously in the literature.

One occurrence, located on Durham County Road 1804, directly north of its junction with Road 1807, was chosen as being the most characteristic for the deposition of laumontite which is directly related to and found in fractures and openings in these basic igneous bodies. At this location, laumontite occurs in a 4" fracture within a diabase dike. Laumontite crystals completely fill the fracture in sheaf-like or divergent radiating groups of crystals with inter-crystal intersticies filled in random fashion with laumontite of a more massive nature. No other minerals were found associated with the laumontite in this fracture filling except that which was formed by weathering of the laumontite and which will be noted later in the paper. The lack of calcite, quartz and other zeolites is noteworthy.

Laumontite Associated with Crystal Tuff

The second occurrence of laumontite crystal deposition to be considered in this report is one which is located north of Durham, North Carolina in a quarry at the end of Durham County Road 1641. At this location it occurs in a fracture system of the low rank metamorphosed Piedmont rocks near their junction with the western border of the Triassic age Durham Sub-basin rocks. Where the Triassic age rocks which were deposited in this area have not been completely removed by erosion, they lie unconformably on the older Piedmont rock mentioned above as either small isolated outliers or as faulted in sections. Late Triassic age diabase dikes (probably offshoots of the larger diabase bodies in the Triassic basin proper) intrude and cut the Piedmont rocks for short distances from the Triassic-Piedmont contact in this area. They have little alteration effect on the Piedmont rocks that they intrude and seem to bear no relationship to this particular deposition of laumontite.

Thin section and X-ray analyses of the Piedmont host rock, from the location where the laumontite occurs, show the rock to be a metamorphosed crystal tuff. It is composed predominantly of quartz clasts throughout which subangular clasts of plagioclase feldspar (andesine to oligoclase) are dispersed.

Fracturing in the Crystal Tuff. Dynamic processes, which were in operation during the late metamorphic phase of the rocks' history, have intricately fractured the rock mass. Epidote, with minor amounts of calcite and chlorite, fills the fractures and replaces the host rock along the fracture systems or, epidote may also occur in isolated areas of replacement within the rock mass. Magnetite grains are dispersed throughout the rock in sheet-like concentrations which traverse the rock in all directions. Some of the magnetite concentrations are associated with the epidote of the fracture systems, being generally peripheral to it. Other concentrations of the magnetite are not associated with epidote and appear to be concentrated along old healed, barren fracture systems. Small amounts of hematite, leucoxene and sericite are scattered randomly through the thin sections with sericite also being present as the alteration product of feldspar clasts.

Laumontite deposition at this occurrence is associated with or confined to late fractures, late in the sense that they cut earlier fracture fillings of epidote but may themselves contain epidote. Both of these type fracture fillings are products of low grade dynamic and chemical metamorphic processes which are late or post tuff consolidation features and may represent two or more isolated processes or simply the continued features of a single changing process.

Depositional Sequence. Megascopic and thin section study of cross sections of the metamorphosed crystal tuff host rock containing laumontite veins was undertaken to determine the depositional sequence of all involved mineral species from within the unaltered host rock to the center of the laumonite depositional veins.

As the fracture systems in which laumontite is deposited are viewed in cross section, small veins filled predominantly with calcite, which cut earlier veins of epidote, appear. They end in the laumontite bearing veins either by termination against the laumontite crystal structure or by junction with the calcite component of the laumontite containing veins. They appear to be a source of the calcite component in the veins.

Massive salmon colored laumontite may randomly replace the host rock a few inches outward into the host rock from any vein. The intensity of replacement usually increased from a few isolated small patches, either within the host body or along a fracture system, to possible complete replacement near and on the fracture surface. It is upon this laumontite replaced surface that deposition takes place in the open fracture.

Calcite first coats the fracture wall. When found in this position it is granular to massive in nature and is free of foreign intergrown crystalline material except for occasional small patches of epidote or laumontite. After this initial thin layer of calcite has been deposited, a single crystal thickness of andradite garnet may form on and from this calcite layer surface. The garnets replace the calcite at the calcite-garnet interface and form outward into the open fracture area with well developed crystal faces. This results in a thin continuous shell of garnet being formed over the calcite surface. It is composed of a composite of individual roughly cup shaped garnet crystal forms at the garnet-calcite interface. The garnet crystal color is from light honey to dark honey, with zones of a brown-black color forming layers in some of the crystals at their outer edges. The thickness of these garnet shells may vary from a quarter of an inch to paper thin, in which last case the color is usually dark and associated with chlorite inclusions.

The last sequence forms on the garnet surface, or directly on the massive calcite surface if the garnet surface is not present. It may consist of large euhedral crystals of calcite or of equant to elongate prismatic euhedral crystals of laumontite or of both of these. The laumontite is white to pale salmon pink in color and may have color shade zones parallel to growth surfaces. It grows in profusion but is generally oriented inward into the fracture opening. It is found both separately and intergrown in and around calcite crystals which formed simultaneously with the laumontite.

Chlorite occurs in the sequence as a companion of epidote and magnetite in the early fractures and also in fault gouge along mineral filled fractures which appear to be later than the laumontite deposition and may, therefore, be post-depositional to laumontite in this case.

Quartz was not found in the sequence of vein minerals except as a minor constituent of the initial epidote veins (see Figure 1).

PHYSICAL PROPERTIES

Those crystals of laumontite from the Durham, N. C. area which are well developed, exhibit forms that are equant to prismatic and enlongate on the C crystallographic axis. They are terminated by an oblique (hol) face and bounded by {110} prism faces. Modification on this form reflects variations in depositional conditions.

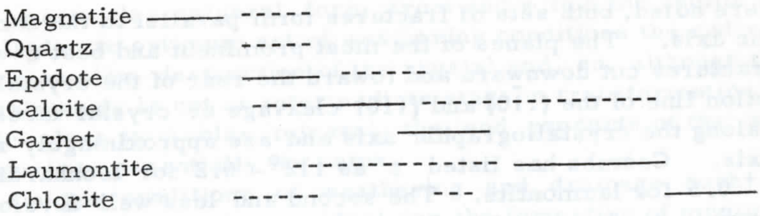

Figure 1. Graphic representation of the possible mineral depositional sequence.

Various prismatic cleavages (100, 110, 010) have been reported for laumontite. Gilbert (1951) reported two cleavages on {110} at approximately 86° in material from Mendocino County, California; but considered continued reference in the literature to cleavage on {010} to be the perpetuation of an original error. Of these, the author found only the {110} prismatic cleavage in the laumontite of this study. A poor {hol} cleavage (or parting) parallel to the oblique terminating crystal face was also present. This cleavage was present in most of the crystals which were examined, sometimes cutting across the entire crystal but most often cutting across only a portion of the crystal, to die out against the much more easily obtained {110} cleavage surface. It was induced in only a few instances with difficulty and then very rarely did it progress across a complete crystal or cleavage piece of crystal. Though the incipient {hol} break does, in most cases, terminate against a {110} cleavage surface, most of the cleavage on {110} is later than the {hol} break because they do not transect the {hol} break. It is assumed, therefore, that the {hol} breaks occurred before the laumontite was laid open to dehydration, or at least early in the dehydration process and may be the normal breakage pattern for laumontite which has not been subjected to conditions of dehydration strain.

Gilbert (1951) and Coombs (1952) both recorded the changes in refractive indices and 2v which were associated with the dehydration-rehydration reaction between laumontite and leonhardite. Coombs also noted that for his material this reaction is accompanied by a change in the (100) lattice spacing of .18Å and in the (010) lattice spacing of .07Å (within ± 0.01-0.02Å). This differential lattice spacing change affects the inter-cleavage angle (110) $\wedge$ (1$\bar{1}$0) from 92.0° to 92.5° respectively for laumontite to leonhardite and is the reason why laumontite crystals fall to pieces along their incipient prismatic cleavage planes during dehydration.

Associated with this lattice change and resultant prismatic cleavage situation in the Durham, N. C. area material is the formation of a unique conjugate set of fractures which, because of their attitude, cause the mineral to break into pointed wedge shaped particles. In the singly terminated and attached crystals of this study, in which fractures were noted, both sets of fractures form parallel to the B crystallographic axis. The planes of the most prominent and best developed set of fractures cut downward and toward the rear of the crystals from the junction line of the $(1\bar{1}0)$ and (110) cleavage or crystal faces when viewed along the crystallographic axis and are approximagely normal to the axis. Coombs has listed β as 112^{o} - 0.2 for leonhardite and $115.5^{o} \pm 0.5$ for laumontite. The second and less well developed set of cleavage cuts downward and forward from the junction line of the $(\bar{1}10)$ and $(\bar{1}\bar{1}0)$ cleavage or crystal faces at a similar but much less well defined angle.

Under the same conditions of dehydration both cleavage and fracture vary in amount and ease wich which they form in the crystals of one occurrence to the crystals of another and also from one crystal to another in a single occurrence. Coombs (1952) considered that the variations in refractive indices due to the effect of the variation in alkali content of laumontite would be hidden by the effect of dehydration, but did suggest that refractive indices drop with an increasing silica-alkali content. A similar trend in the reduction of refractive index values was noted in this study on the less easily cleavable or broken particles and this may be related in turn to a variation in chemical composition. Fersman (1908) found a relationship between leonhardite with high alkali content and no (010) cleavage, and β-leonhardite with good (010) cleavage and loss of water. Although Fersman's (010) cleavages do not appear to be valid, the relationship between cleavage, preferential dehydration and alkali content may be real though complex. Further work is being done along this line.

WEATHERING

The two step alteration of a high glass containing tuff to clinoptilolite and then to hectorite under the influence of hot spring activity has been discussed by Ames et. al. (1958). Bramlette and Posnjak (1933) have shown that clinoptilolite constituted an intermediate stage in the change from a pyroclastic material to bentonite in Miocene deposits. Other occurrences of zeolites in bentonite deposits have been reported from time to time in the literature. Change of a zeolite to bentonite is, therefore, not unique.

In this study the exposure, due to erosion, of pockets and fractures in Triassic age basic intrusives which contain laumontite have given an insight into the process and products of the weathering of this zeolite. Where these pockets of laumontite are isolated by poor drainage conditions, the weathering products form and remain in place.

Although minor destruction from the weathering process does occur on the individual laumontite crystal face surface, on cleavage and fracture surfaces or on incipient cleavage planes within the crystal, the predominance of breakdown proceeds almost wholly in a random fashion across the crystal structure. Microscopic and megascopic vermiform aggregates and rounded irregular patches of trans-parent green clay mineral form from and within the zeolite crystal body. Under an optimum set of weathering conditions the end result is complete random destruction of the crystal and, so, although the zeolite of this study is not an intermediate stage in transformation from a volcanic glass to a clay mineral, the end products of the zeolites breakdown are essentially the same.

Unique conditions of weathering and drainage such as just described for this study are ideal for the formation of montmorillonites from laumontite. The potential availability of both calcium and magnesium is high. Calcium can be derived not only from the parent zeolite, but from the breakdown of the feldspars of the enclosing host diabase body.

Table 1. Static Temperature X-ray Data for Leonhardite

Endothermic 127° C peak; Endo. 271° C; Endo. 468° C; Endo. 832° C; Endo. 890° C; Endothermic 1106° C peak

Leon.-xl. Salmon pink		X-ray at 190°C Pink-xl. leon.		X-ray at 340°C Pink-xl.+w+ph		X-ray at 560°C Pink-xl. w+ph		X-ray at 870°C Light pk. Am+ph.		X-ray at 970°C Light pk. Am+ph		X-ray at 110°C gray white-xl. An + am.	
				10.72		10.75							
9.48	80	9.48	85	9.46	100	9.56							
				8.59	65	8.53	85	8.63	05	8.71	05		
6.85	25	6.85	55	6.82	35								
6.55												6.43	
				6.32		6.31							
6.20		6.17		6.11									
5.91													
				5.57		5.54	35						
				5.39		5.36							
5.05		5.04		5.03									
						4.85							
4.74		4.74		4.73	25	4.77	15						
4.50		4.49		4.46									
4.31		4.31				4.30							
4.16	55	4.16	55	4.16	30	4.22						4.03	15
						3.83							
3.867		3.867											
3.770		3.770		3.758									
				3.712		3.704	15	3.70	D	3.70	D	3.712	20
3.659		3.659		3.626									
3.510	30	3.510		3.520		3.551						3.453	
				3.469								3.405	
3.408		3.408		3.398		3.414	20						
3.360		3.360										3.273	
3.270		3.278	25	3.284								3.223	30
										3.198	05	3.200	50
3.200		3.200		3.195								3.181	
3.150		3.150		3.158								3.118	30
3.089		3.092		3.082									
3.035	60	3.033	25	3.033		3.061						2.996	

Leon. = Leonhardite
W. = Wairakite
Am. = Amorphous
Ph. = Phase
An. = Anorthite

Magnesium is available from the breakdown of magnesium bearing minerals in the diabase. Under the conditions of poor drainage or circulation the concentration of these ions could be rather high. The paucity of potassium ions is also commensurate with the formation of montmorillonite and almost complete lack of potassium was noted by Hermes (1964) in the dolorite groups of the Deep River Basin.

The breakdown of zeolites to clay products in this fashion might help explain the spatial distribution and perimeters of certain other authigenic or more massive zeolite deposits. This alteration would especially account for the lack of zeolite mineralization where it might otherwise be expected to occur. The alteration conditions in force during weathering and the original zeolite mineral would be major factors in determination of the resultant end product.

X-RAY AND DTA DATA FOR SAMPLE N. T. 107

Dessicated laumontite, designated as N. T. 107, from the second discussed occurrence, gave an X-ray diffraction pattern which was a composite of all of the d spacings listed for leonhardite by both Coombs (1952) and Lapham (1963). The most intense reflection was at 9.48Å and an additional weak peak at 3.86Å was found. This material, which was hand picked, acid washed and dessicated for a month over silica jell before being X-rayed was also used for DTA and static temperature X-ray diffraction products (see Table 1). Comparison of the resulting data and the data of Koizumi (1953) for DTA and dehydration curve studies for laumontite was undertaken.

The DTA curve of N. T. 107 shows one first order intensity endothermic peak, four second order intensity endothermic peaks and one first order intensity exothermic peak. (See Figure 2).

The first reaction gave a broad U-shaped, first order intensity endothermic curve which started at 70° C, peaked out at 127° C and ended at 210° C. A slightly depressed plateau area is evident between about 40° C and 70° C. The area between 40° C and 210° C roughly corresponds to, but does not correlate well with, the DTA curve of Koizumi (1953) for laumontite. He found a major endothermic peak at 71° C and considered it to represent correspondence with the first of three dehydration steps shown by his laumontite dehydration curve. A small subsidiary peak can be seen on Koizumi's DTA pattern at approximately 120° C to 125° C. This may correspond to and represent the major peak of the N. T. 107 material at 127° C while the plateau of the N. T. 107 material may correspond to and represent Koizumi's major peak at 71° C. Pe.g (1955) has shown that peak shift and variation in peak intensity for both endothermic and exothermic reactions of some zeolites may occur as a result of the variation of particle size, composition and other factors. Incomplete dehydration of laumontite to leonardite could also affect the low temperature area of the DTA record. Pagliani (1948) reported that laumontite partially dehydrates at 70° C which is very similar to Koizumi's peak at 71° C. Material used in this study (N. T. 107) for DTA study had been dehydrated to leonardite as shown by the X-ray diffraction pattern.

Further, the 127° C peak of the N. T. 107 sample is consistent with the shoulder location of the first dehydration step on Koizumi's dehydration curve. It would probably represent the removal of loosely

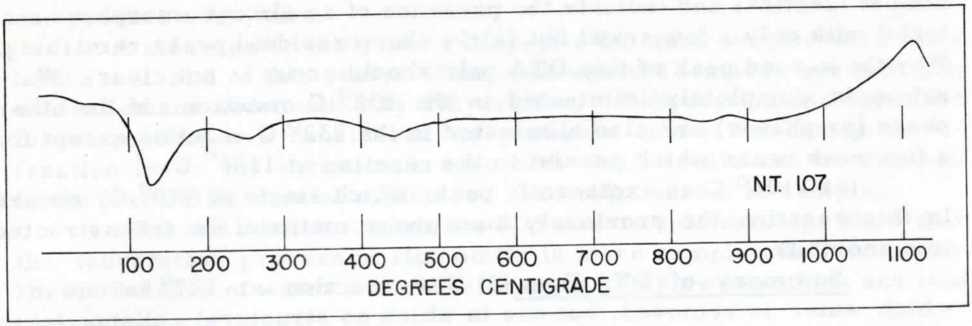

Figure 2. Differential thermal analysis curve for leonhardite. 12.5° C/min.

held water which remained after the initial dehydration from laumontite to leonhardite had taken place. This would be indicated because the X-ray diffraction patterns of unheated leonardite and leonhardite heated to 190° C (past the 127° C peak) show no structural change.

The second DTA peak of the pattern is a broad, subdued endothermic one which starts at 210° C, peaks out at 271° C and returns to base line at 340° C. Although it is a subdued peak, the static X-ray diffraction pattern which was taken at 340° C shows that at least three crystalline phases are present. The 9.48Å (9.46Å) and 6.85Å (6.82Å) lines of the leonhardite X-ray diffraction pattern remain the two most intense lines at this stage. Although most of the other leonhardite lines remain in the pattern they do show minor shifting and deleation. This shift of d spacings in the still present leonardite pattern could represent a removal of water with minor but not complete collapse of the structure to a new phase. Wairakite is the second phase present. In the case of the formation of Wairakite, one and one half waters have been removed in two dehydration steps from the leonardite structure and a shift in lattice dimension would have had to take place to form the new (pseudo-cubic) Wairakite structure. A third unidentified phase (or phases) also exists at this point. Formation of this phase could represent either a weak endothermic or an exothermic reaction. If it is an exothermic reaction its peak has been masked out and absorbed by the simultaneous occurrence of the endothermic peak. This second DTA peak at 271° C correlates very well with the second shoulder of Koizumi's dehydration curve for laumontite.

An endothermic reaction at 468° C represents further dehydration, with almost complete elimination of leonhardite. Wairakite and the other crystalline phase are strongly intensified. This reaction gives a moderately weak DTA peak of the intensity of the 271° C reaction but of longer duration. It corresponds very well with the third step of Koizumi's dehydration curve which extends from 200° C to 700° C.

Small endothermic peaks occur at both 832° C and 890° C.

Static X-ray diffraction patterns at 870° C and 970° C respectively are almost identical and indicate the presence of an almost amorphous material with only a few small but fairly sharp residual peaks remaining. Why the second peak of this DTA pair should occur is not clear. Wairakite is completely leiminated in the 832° C reaction and the other phase (or phases) are also eliminated in the 832° C reaction except for a few weak peaks which persist to the reaction at 1106° C.

At 1106° C an exothermic peak, which starts at 970° C, occurs. In this reaction the previously amorphous material is reconstructed into anorthite.

Summary of DTA Data (1) The reaction at 127° is one in which water is removed, but one in which no structural collapse takes place. Easily removed water is indicated. (2) At the 271° C reaction further water is removed to form Wairakite and an unidentified phase (or phases). Some leonhardite remains after this reaction but a slight shift in spacing indicates a structure change. Removal of water is indicated here in the formation of Wairakite in which case one and one half waters would have been removed in the first and second reaction. The change in structure of remaining leonhardite would also indicate removal of water but not to the point of structure collapse. (3) At 468° C a reaction occurs in which complete elimination of leonhardite takes place and Wairakite and the unidentified phase (or phases) take over. At this point no more than two waters can remain in the existing crystalline structures, with probably less in the unidentified crystalline phase. This last idea is reinforced by the complete elimination of Wairakite at 832° C but of the persistence of the unidentified phase to remain as a minor constituant in the amorphous phase produced at 832° C. (4) Complete elimination of Wairakite and almost complete elimination of the unidentified phase to an amorphous state takes place at 832° C. The reaction at 890° C produces no visible results and complete change occurs at 1106° C to form reconstructed anorthite. All reactions are slow and cover a broad range of temperature conditions. Further, the sequence of water volume elimination and phase change is telescoped over a long range instead of being in definite increments as it is in some of the other zeolite mineral species.

CONCLUSIONS

The occurrence of laumontite in an calcite-epidote-magnetite-garnet assemblage formed as a result of metamorphism and metasomatism in a crystal tuff is similar to the assemblage found by Sumin (1955) in a skarn and tends to delineate the parameters of formation conditions by association.

The weathering of laumontite completely to a montmorillonite clay mineral was noted. Weathering of the zeolites to clay minerals could account to a degree for their special distribution. Physical and chemical conditions to which they were subjected during breakdown and the type of zeolite mineral involved would influence the form the end product would take.

A cleavage on (hol) and a conjugate fracture system were noted on the material of this study. Both cleavage and fracture are partially controlled and accentuated by dehydration. Dehydration and variation in composition are considered as probable causes for change in refractive index and variation in ease with which breaks can be obtained in the laumontite crystal structure. The relationship is complex.

DTA and static temperature X-ray data relationships show that the dehydration process of laumontite is more complex than most zeolites. Release of water and phase changes are slow reactions and tend to overlap.

REFERENCES

Ames, L. L., Jr., Sand, L. B. and Goldich, S. S., 1958, A contribution on the Hector, California bentonite deposit: Econ. Geol., v. 53, p. 22-37.

Bramletee, M. N. and Posnjak, E., 1933, Zeolitic alteration of pyroclastics: Am. Mineral., v. 18, p. 167-171.

Coombs, D. S., 1962, Cell size, optical properties and chemical composition of laumontite and leonhardite: Am. Mineral., v. 37, p. 812-830.

Coombs, D. S., Ellis, A. D., Fyfe, W. S. and Taylor, A. M., 1959, The zeolite facies, with comments on the interpretation of hydrothermal synthesis: Geochim. et. Cosmochim. Acta, v. 17, p. 53-107.

Deer, W. A., Howie, R. A. and Zussman, J., 1963, Rock forming minerals: v. 4, p. 351-428, John Wiley and Sons, Inc., N.Y.

Des Cloizeaux, A., 1862, Manuel de Mineralogy: Paris, p. 402-406.

Gilbert, C.M., 1951, Laumontite from Anchor Bay, Mendocino County, California: Bull. Geol. Soc. Am., v. 62, p. 1517, (abst.).

Hermes, O. D., 1964, A quantitative petrographic study of dolerite in the Deep River Basin, North Carolina: Am. Mineral., v. 49, p. 1718-1729.

Koizumi, M., 1953, The differential thermal analysis curves and the dehydration curves of zeolites: Min. Jour. (Japan), v. 1, p. 36-47.

Lapham, D. M., 1936, Leonhardite and laumontite in diabase from Dillsburg, Pennsylvania: Am. Mineral., v. 48, p. 683-689.

Pagliani, G., 1948, Le zeolite del granito di Baveno: Periodico Min. Roma, v. 17, p. 175-188.

Peng, C. J., 1955, Thermal analysis study of the natrolite group: Am. Mineral, v. 40, p. 834-856.

Sumin, N.G., 1955, On laumontite from Dashkesan: Trans. Min. Mus. Acad. Sci. U.S.S.R., v. 7, (Min. Abstracts, v. 13, p. 189).

ULTRAMYLONITE ZONES IN THE WESTERN CAROLINAS

by

James F. Conley
and
Kenneth M. Drummond
North Carolina Department of Conservation and Development
Division of Mineral Resources

ABSTRACT

A number of northeast trending, narrow, dike-like zones of flinty ultramylonite occur in the Piedmont and Blue Ridge regions of Burke, Rutherford, Polk, and Henderson Counties in North Carolina and Spartanburg and Greenville Counties in South Carolina. These ultramylonite zones are a few hundred feet to 27 miles in length and are 2 1/2 to 300 feet wide. They are relatively uniform in appearance, composition, and texture even though they are enclosed by a diverse assemblage of Inner Piedmont rocks.

The ultramylonite is composed of indurated, cryptoclastic rock and mineral particles that consist of sheared quartz grains, feldspar, sericite, kaolinite, and a dark material of glassy aspect. The ultramylonite has been silicified and finely veined as well as coarsely brecciated and healed by quartz veins.

The ultramylonite zones probably developed along major lateral faults during Triassic time. Subsequent movement, probably during Tertiary time, caused brecciation of the ultramylonite.

INTRODUCTION

Narrow, dike-like zones of massive, non-laminated, flinty mylonite and mylonite breccia, which might best be described as ultramylonite, can be traced for considerable distances in the Piedmont and Blue Ridge regions of North and South Carolina. The term ultramylonite as used in this paper is defined in the A.G.I. Glossary of Geology and Related Science (1957) as, "A homogeneous mylonite, free of all parallel structures". Ultramylonite is considered to be the product of intense and rapid milling in a fault zone (Tyrrell, 1929). It is thought to form at depths where the confining pressure is sufficient to maintain cohesion in the rocks undergoing shearing (Waters and Campbell, 1935). Ultramylonites have been reported in normal, thrust, and lateral faults (Shand, 1931; Waters and Campbell, 1935).

Although one isolated outcrop of ultramylonite was observed by the senior author as early as 1956, the linear continuity and widespread occurrence of the ultramylonite zones was not recognized until the writers initiated a regional field mapping program. The occurrence of the ultramylonite zones was reported in 1963 (Conley and Drummond, 1963, p. 241), however, limited field investigations at that time caused the authors to consider their uniformity of appearance, when cutting across diverse rock types, as indicating that they were fault controlled felsite intrusives which had been brecciated. Recently completed detailed mapping of that part of the Inman quadrangle in North Carolina and reconnaissance mapping of the surrounding area has revealed twenty-two of these zones and has produced evidence which indicates that they developed by milling during fault movement. These zones are now known to occur in a wide belt which can be traced through Burke, Rutherford, Polk, and Henderson Counties in North Carolina, and Spartanburg and Greenville Counties in South Carolina. All of the ultramylonite zones herein described occur in rocks which are assigned to the Inner Piedmont suite of King (1955). However, the occurrence of these zones may be widespread, as a speciment of ultramylonite similar to those described in this report was collected by W. T. McDaniel from near the northern city limits of Greensboro. This specimen suggests that ultramylonite zones might also occur in the Charlotte Igneous Belt. In addition, Crickmay (1933) described mylonites similar to the ultramylonite of this paper in the crystalline rocks of Georgia.

Acknowledgments

The authors wish to thank W. T. McDaniel, North Carolina State Minerals Research Laboratory, for his assistance. Special thanks are extended for his having provided transportation for several field trips.

P. N. Sales, North Carolina State Minerals Research Laboratory, chemically analyzed several specimens. W. C. Ashley, Saluda, North Carolina, showed the authors several outcrops which facilitated tracing out one of the ultramylonite zones. Mrs. Louise Matthews graciously typed the manuscript.

DESCRIPTION

The ultramylonite zones are 2 1/2 to 300 feet wide. They occur as individual zones, in pairs, and as rude, fan shaped swarms. They are resistant to erosion, forming elongate hills in the Piedmont and holding up lesser hills in the Blue Ridge. They can be traced overland from a few hundred feet to a few miles, and one has been traced over 27 miles. All of the zones trend in a northeasterly direction, and are either vertical or inclined to the southeast at a high angle.

The ultramylonite zones occur in a variety of host rocks, including granites, gneisses, and schists. Most of them exhibit a rude,

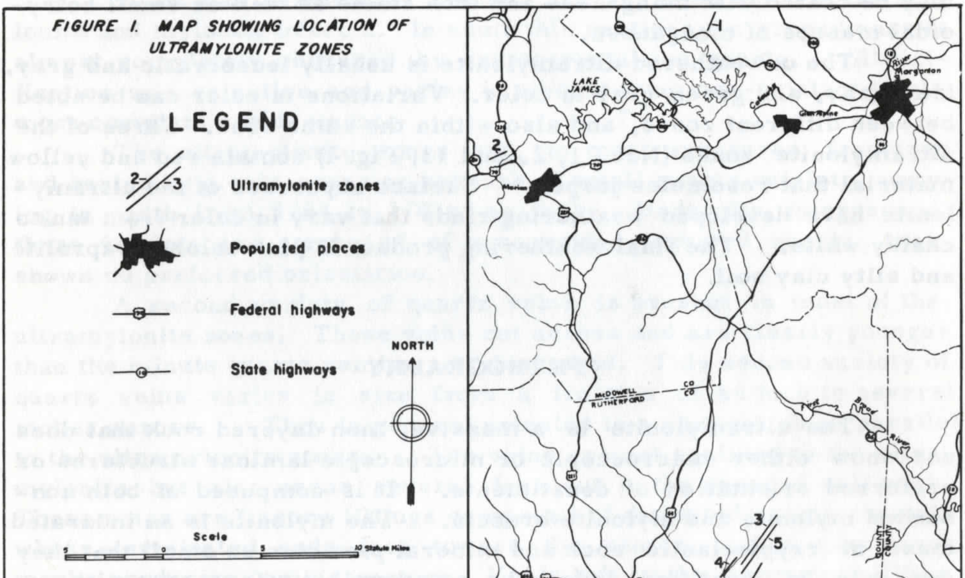

Figure 1. Map showing location of ultramylonite zones.

lithologic zoning. The center usually consists of flinty mylonite and mylonite breccia, that grades outward into crushed wall rock, and finally into well foliated, relatively unaltered wall rock. The point of juncture between the crushed wall rock and the ultramylonite is usually a distinct contact. Drag folds in the ultramylonite and country rock were not observed.

Jointing is usually well developed in the ultramylonite zones and poorly developed in the country rock. Joint and fracture surfaces may be coated with manganese and iron stains as well as small botryoidal masses of manganese.

The unweathered ultramylonite is usually leucocratic and gray, blue-gray, and green-gray in color. Variations in color can be noted between different zones, and also within the same zone. Three of the ultramylonite zones (Nos. 1, 2, and 13; Fig. 1) contain red and yellow material that resembles jasper. Surface exposures of the ultramylonite have developed weathering rinds that vary in color from tan to chalky white. The final weathering product is pink colored saprolite and silty clay soil.

PETROGRAPHY

The ultramylonite is a massive, non-layered rock that does not show either macroscopic or microscopic laminar structures or preferred orientation of constituents. It is composed of both non-banded mylonite and mylonite breccia. The mylonite is an indurated mass of cryptoclastic rock and mineral particles so small that they can only be identified under the petrographic microscope with extreme difficulty. The groundmass of the mylonite is composed of cryptocrystalline quartz with a subordinate amount of high birefringent material, probably sericite, a low birefringent material, probably kaolinite, and a cryptocrystalline non-polarizing material. This groundmass contains many isolated, larger, angular to subrounded particles of feldspar and quartz. Some of the feldspars still show albite twinning. The quartz fragments exhibit a high degree of internal fracture, undulatory extinction, and a generally cloudy appearance. No preferred orientation of the quartz was noted.

Three of the ultramylonite zones (Nos. 2, 4, and 5; Fig. 1) contain narrow, dike-like bodies of medium to dark gray mylonite that vary in thickness from a few inches to over a foot. These bodies contain dark gray, wispy shards and minute, white, angular fragments that cause the rock to strikingly resemble a porphyritic volcanic rock. Similar material, occurring in mylonites, has been called pseudotachylyte in the literature (Shand, 1931). Pseudotachylyte is considered to be a partially vitrified rock that forms only under conditions of extreme milling, although recent evidence indicates that it might not have reached a state of fusion (Williams, Turner, and Gilbert, 1954).

The mylonite breccia consists of angular fragments, ranging in size from 1/16 to 1/2 inch in diameter. The fragments are mainly composed of unbanded mylonite and pseudotachylyte, with minor amounts of banded mylonite, granulated quartz, feldspar, and granite. The fragments are usually embedded in an unbanded mylonitic groundmass, but in some instances the groundmass is lacking, and the breccia is healed by a network of quartz veins.

Silica has permeated, healed, and replaced much of the mylonite and mylonite breccia. In some thin sections the groundmass is almost completely obscured by cryptocrystalline quartz. Silicification was selective and varies in amount from non-existant to almost complete replacement.

The ultramylonite zones are, in most exposures, fractured and healed by a cris-crossing network of small quartz veinlets, varying in width from 1/64 to 1/4 of an inch. Under the microscope these veinlets are composed of saccaroidal textured quartz that shows no preferred orientation.

A second variety of quartz veins is present in most of the ultramylonite zones. These veins cut across and are clearly younger than the minute quartz veining just described. This second variety of quartz veins varies in size from a fraction of an inch to several inches across. They in general oriented in a vertical plane parallel to the ultramylonite zones. The veins are not confined to the ultramylonite but also occur several feet out in the sheared wall rock. These veins are fissure fillings composed of distorted quartz crystals whose terminated ends face toward the center, and in most cases mesh, producing comb structure. Voids left by the incomplete filling of the fissures may be filled with either boxwork quartz or onyx or both. The banding of the onyx in a number of occurrences is parallel to a horizontal plane, suggesting that the onyx was deposited by a fluctuating water table. In other instances the onyx bands parallel the planar surfaces of the boxwork quartz.

HEAVY MINERALS

A heavy mineral concentrate was prepared from ultramylonite saprolite collected from an ultramylonite zone that is enclosed by granite (No. 18, Fig. 1). This concentrate consisted mainly of pyrite; limonite, pseudomorphic after pyrite; a small amount of black manganese minerals; and a trace of chlorite, epidote, and zircon. Because the morphological characteristics of zircons have been used to indicate petrogenesis of igneous and metamorphic rocks, (Larsen and Poldervaart, 1957; Reed, 1937; Poldervaart, 1955; and Poldervaart, 1956) the heavy mineral suite was subjected to a hydrofluoric acid leach and the zircons thus concentrated were studied to see if

Figure 2. Photograph of typical exposure of ultramylonite showing its well jointed and dike-like structure.

they had been markedly altered by the milling processes that produced the ultramylonite.

The zircon fragments average about .13 mm in length and .06 mm in breadth. They are colorless under reflected light, but assume a rose hue under plane polarized light. They show much breakage, rounding of crystal faces, and internal shattering. The doubly terminated, sharp angular faced zircons of undisturbed igneous rocks were not observed. Overgrowths and phantom structures, common in metamorphic rocks, are also absent. The fragmental nature, rounded crystal faces, and internal shattering is explained as a product of granulation. Therefore, it is concluded that the zircons nucleated and grew in a plutonic-igneous environment and were markedly broken and abraded during the period of cataclasis which produced the ultramylonite.

CHEMICAL ANALYSIS

Samples of ultramylonite from four outcrops were analyzed to determine whether or not the gross diversity of composition of the parent rocks would be reflected in the composition of the ultramylonite. Sample No. 1 was collected from ultramylonite enclosed by sillimanite schist, Sample No. 2 by granite, Sample No. 3 by migmatized hornblende gneiss, and Sample No. 4 by biotite gneiss. The surprisingly uniform composition can be explained by the anomolously high SiO_2 content that is due to silicification and quartz veining. The extremely low percentages of the other constituents and their ratios to each other further suggests that silicification was not only a cementing but also a replacement process.

Table 1. Chemical Analyses of Four Ultramylonite Zones

Sample	SiO_2	Al_2O_3	Fe_2O_3*	Na_2O	K_2O	Ign. Loss	CaO	MgO
1	93.9	3.2	0.71	0.07	0.71	1.29	Nil	Nil
2	94.0	3.6	0.47	0.05	0.47	1.44	"	"
3	93.6	4.8	0.43	0.14	0.43	0.89	"	"
4	97.7	1.3	0.27	0.08	0.27	0.60	"	"
Average	94.8	3.2	0.47	0.09	0.47	1.06	Nil	Nil

* Total iron content reported as Fe_2O_3.

Enclosing rock
1. sillimanite schist
2. granite
3. migmatite
4. biotite gneiss

Analyst
P. N. Sales
North Carolina State
Mineral Research Laboratory
Asheville, North Carolina

TECTONICS

In general there is strong evidence for five major episodes in the development of these ultramylonite zones. Even though certain episodes may be stronger, weaker, or lacking from zone to zone or along strike of the same zone, these events appear to have taken place in a chronological order. This sequence is summarized below:

(1) Mylonitization along a fault zone. The degree of deformation probably varied from coarse brecciation of the country rock to complete granulation and development of ultramylonite and pseudoachylyte.

(2) Silicification.

(3) Fracturing and development of network of minute quartz veinlets.

(4) Brecciation. Brecciation was accompanied by the development of open fissures and cavities which were partially to completely filled by crystalline quartz veins.

(5) Development of boxwork quartz and onyx in the remaining cavities.

Whether or not these episodes represent major or minor time intervals is open to question. However, it is suggested that the interval between mylontization and brecciation could have been of long duration. The reason for this suggestion is the fact that one of the ultramylonite zones occurs at the base of the Blue Ridge front in the area where W. A. White (1950) proposed the existance of a Tertiary normal fault that can be traced over 700 miles by following six systematic left handed offsets of 2 to 10 miles displacement. He suggested that the movement along this fault utilized preexisting Triassic structures to produce the Blue Ridge front. This same ultramylonite zone is also located at the western contact of a large shear zone that Reed et. al. (1961) called the Brevard fault and dated as post Paleozoic thrusting and pre-(late) Triassic igneous activity. They suggested that the major movement in the fault was lateral, but that regional geologic considerations dictated some vertical displacement. They noted that the shear zone trends northeast and dips to the southeast at 40 to 60 degrees. The ultramylonite zone parallels the shear zone, but is oriented in a near vertical position.

In regard to this later interpretation, Moody and Hill (1956) have proposed that most major faults that can be traced linearly over long distances are actually lateral faults in which there could be vertical movement. They state "Thus it should be fairly common to see vertical-fault systems which satisfy the direction of a theoretical wrench-fault system but on which the later increments of movement have been essentially vertical. Such faults having the appearance of high-angle normal or reverse faults, may have originated as wrench faults in response to horizontal compressive stresses." In this group they include the Triassic basins of the Appalachians which are considered to be caused by normal faulting. They further point out that recent vertical movement has been observed in a number of known lateral faults and that later vertical movement has obscured the lateral nature of many faults.

Hill and Dibblee (1953) have noted that lateral faults are characterized by vertical to high angle dips, long linear character, an echelong and parallel traces, and offset drainage. Moody and Hill (1956) suggested that any fault plane with an angle of dip greater than 70 degrees should be examined for lateral displacement. The absence of drag folds, inability to match lithology on either side of the fault, and lack of preferred orientation of rock and mineral grains, especially quartz, makes it difficult to determine the relative direction of the movement which produced the ultramylonite zones. However, in view of the high angle of dip, long linear character, en echelon and parallel traces, offset drainage (Fig. 1), as well as regional geologic consideration; it is suggested that the ultramylonite zones were produced in great lateral faults which represent a major tectonic feature of the Southern Appalachians.

The ultramylonites are obviously younger than their host rocks which have been variously dated as Precambrian (Keith and Sterrett, 1931) and Paleozoic (?) (Overstreet, Yates, and Griffitts, 1963). They are also younger than the latest period of Inner Piedmont deformation as they transect regional folds and tectonic foliations and do not appear to be offset by younger faults. In addition, they show no evidence of having been metamorphosed. It is suggested that the faulting that produced the ultramylonite was probably coincident with Triassic faulting. It is further suggested that later vertical movement, coincident with the development of the Blue Ridge front during Tertiary time, caused the brecciation of the ultramylonite. Indeed, the Brevard fault, the Blue Ridge front fault, as well as the faults which produced the ultramylonite are probably segments of a major system of Triassic faults whose major movement was lateral, but which also undoubtedly displayed a vertical component.

ECONOMIC GEOLOGY

The ultramylonite zones have been used for road metal and a number of borrow pits are located in these deposits. Upon slight weathering they break down into aggregate which can be used with a minimum of preparation. After unweathered rock is encountered these deposits become harder to work and are usually abandoned.

Onyx and mylonite breccia are mined on a small scale by mineral collectors from the ultramylonite zone which crosses U. S. Highway 176, southeast of Saluda, North Carolina. A number of these zones might produce polished ornamental building stone, and some could have possibilities as facing aggregate in decorative faced precast concrete slabs.

Pyrite was noted in the heavy mineral concentrate made from one of the mylonites. Although widespread mineralization was not observed in the ultramylonite zones; their character, token mineralization and regional extent suggests a possibility of the existence of metallic deposits in these zones. It is interesting to note that the ultra mylonite zones occur in a major gold mining district that Nitze and Hanna (1896, p. 162) called the southern extension of the South Mountains gold belt.

REFERENCES CITED

Conley, J. F., and Drummond, K. M., 1963, Brecciated dikes in the Southern Piedmont and mountain regions of North Carolina: abstract, Geol. Soc. America, Special Paper 76, p. 241.

Crickmay, G. W., 1933, The occurrence of mylonites in the crystalline rocks of Georgia: American Journal of Science, v. 26, p. 161-177.

Hill, M. L., and Dibblee, T. W., Jr., 1953, San Andreas, Garlock, and Big Pine Faults, California: Bull. Geol. Soc. America, v. 64, p. 443-458.

Howell, J. V., 1957, Glossary of geology and related sciences: American Geological Institute, Washington, D. C., 324 p.

Keith, A., and Sterrett, D. B., 1931, Gaffney-Kings Mountain folio: U. S. Geological Survey, Geological Atlas (no. 222), 13 p.

King, P. B., 1955, A geologic section across the southern Appalachians: an outline of the geology in the segment in Tennessee, North Carolina, and South Carolina, In Russell, R. J., ed., 1955, Guides to Southeastern Geology: Geol. Soc. America Guidebook, 1955 Ann. Mtg., p. 332-373.

Larsen, L. H., and Poldervaart, A., 1957, Measurement and distribution of zircons in some granitic rocks of magmatic origin: Mineralogical Magazine, London, v. XXXI, no. 238, p. 544-564.

Moody, J. D., and Hill, M. J., 1956, Wrench-Fault tectonics: Bull. Geol. Soc. America, v. 67, p. 1207-1246.

Nitze, H.B.C., and Hanna, G. B., 1896, Gold deposits of North Carolina: N. C. Geological Survey, Bull. 3, 198 p.

Overstreet, W. C., Yates, R. G., and Griffitts, W. R., 1963, Geology of the Shelby Quadrangle, North Carolina: Miscellaneous Geologic Investigations, U. S. Geological Survey Map I 384.

Poldervaart, A., 1955, Zircons in rocks. 1. sedimentary rocks: American Journal of Science, v. 253, p. 433-461.

Poldervaart, A., 1956, Zircons in rocks. 2. igneous rocks: American Journal of Science, v. 254, p. 521-554.

Reed, J. C., 1937, The study of accessory minerals in igneous and metamorphic rocks: American Mineralogist, v. 22, p. 73-84.

Reed, J. C., Jr.; Johnson, H. S., Jr.; Bryant, B.; Bell, H., III; and Overstreet, W. C., 1961, The brevard fault in North and South Carolina: Geological Survey Research 1961, U. S. Geological Survey Professional Paper 424-C, p. C67-C70.

Shand, S. J., 1931, The study of rocks: Thomas Murby and Company, London, 236 p.

Tyrrell, G. W., 1929, The principles of petrology: E. P. Dutton and Co. Inc., New York, 2nd ed., 349 p.

Waters, A. C., and Campbell, C. D., 1935, Mylonites from the San Andreas fault zone: American Journal of Science, v. 29, p. 473-503.

White, W. A., 1950, Blue Ridge Front--A Fault Scarp: Bull. Geol. Soc. America, v. 61, p. 1309-1346.

Williams, H., Turner, F. J., and Gilbert, C. M., 1954, Petrography an introduction to the study of rocks in thin sections: W. H. Freeman and Co., San Francisco, 604 p.

PETROGRAPHY OF THE SOAPSTONE DEPOSITS NEAR OLD DOMINION, ALBEMARLE COUNTY, VIRGINIA

by

S. S. Greenberg
West Chester State College
Pennsylvania

and

R. C. Milici
Tennessee Division of Geology
Knoxville

ABSTRACT

Approximately 200 samples were collected from soapstone deposits and associated rocks in the vicinity of Old Dominion, southeastern Albemarle County, Virginia. The samples were grouped into rock types by means of X-ray analyses and thin section studies. Phyllites and metamorphosed graywackes of the Precambrian Lynchburg Formation enclose a metamorphosed sill that is about 900 feet thick. In this body hornblende-oligoclase rock grades upward into rock consisting predominantly of hornblende, oligoclase, clinozoisite, and muscovite. Chlorite-tremolite rock and chlorite-talc rock are the principal types of soapstone within the sill. Mineralogic classification of rock types is preferable to such terms as metagabbro, metapyroxenite, greenstone, and soapstone.

INTRODUCTION

Previous Investigations

Soapstone deposits generally are found as elongate masses within folded and metamorphosed sandstone, metamorphosed graywackes, and phyllites of the Precambrian Lynchburg Formation. In Virginia the Lynchburg Formation unconformably overlies metaigneous and metasedimentary rocks of the Virginia Blue Ridge Complex, and from Campbell County northeastward parallel to the regional strike the

Lynchburg is overlain by metamorphosed mafic volcanics of the Catoctin Formation. Table 1 shows the generalized stratigraphy.

The deposits in Virginia were described in a general way by Burfoot (1930), and Hess (1933) examined in detail the lithology and mineralogy of the deposits at and near Schuyler, to the south of the Old Dominion deposits (Fig. 1). Bloomer and Werner (1955, p. 593) described the regional relationships of intrusive mafic and ultramafic rocks "in the Lynchburg Formation and basement complex in the great anticlinal fold between the two main belts of the Catoctin Formation in central Virginia". Brown (1958, p. 45) discusses the soapstone and related rocks near the top of the Lynchburg Formation near Lynchburg, Virginia. Fairley and Prostka (1958) prepared a preliminary geologic map of soapstones in Albemarle and Nelson Counties (Fig. 1). They mapped Lynchburg Formation, metagabbro, metapyroxenite, serpentinite, soapstone, and greenstone at and near Old Dominion, Virginia. The purpose of the present investigation is to assign a more objective and more descriptive terminology to rock of the Old Dominion soapstone deposit (Fig. 1) than that used by earlier workers, and to describe generally the relationships of the rock types thus defined to each other.

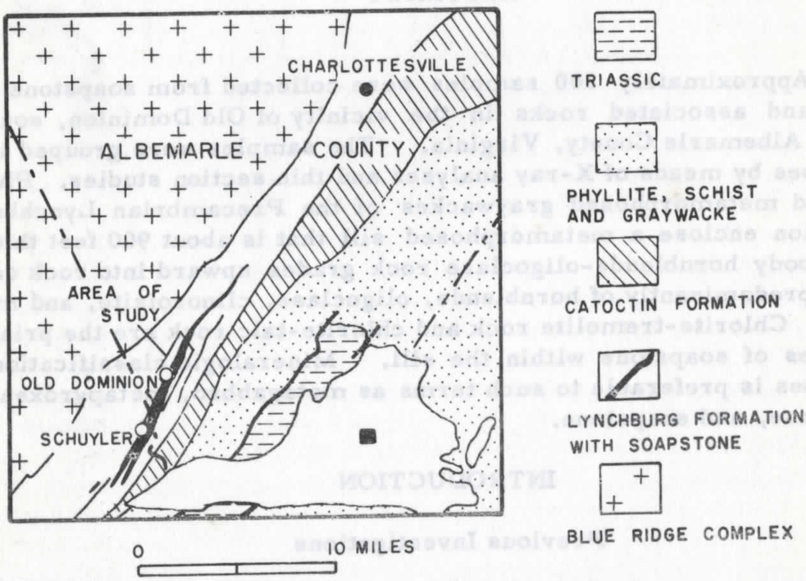

Figure 1. Map of Central Virginia showing location of area studied.

Acknowledgments

R. M. Allen of Louisiana Polytechnic Institute, R. O. Bloomer of St. Lawrence University, and W. R. Brown of the University of Kentucky critically reviewed the manuscript. Harry Giles assisted the

Table 1. Generalized stratigraphic sequence in the vicinity of Old Dominion, Virginia.

Age	Name	Lithology
Early Paleozoic		Phyllite, schist, and metamorphosed graywacke
Late Precambrian	Catoctin Formation	Metamorphosed basalt
	Lynchburg Formation	Metamorphosed graywackes and sandstones, phyllites, and soapstone deposits
Early Precambrian	Virginia Blue Ridge Complex	Igneous and metamorphic basement rocks

writers in the sampling of the quarry at Old Dominion. The study was pursued under the auspices of the Virginia Division of Mineral Resources, James L. Calver, Commissioner.

THE OLD DOMINION SOAPSTONE DEPOSITS

Method of Study

The Old Dominion soapstone deposits were mapped within a metamorphosed pluton that is concordant with bedding in the Lynchburg Formation in southeasternmost Albemarle County, Virginia. This sill is about 900 feet thick and is folded into northeastward plunging anticlines and synclines (Fairley and Prostka, 1958). The outcrop pattern of the sill resembles that of a single anticline, but the northwestern limb of the anticline turns up sharply and only the basal portions of the body are preserved in a shallow syncline (Figure 2).

Approximately 200 samples were collected and analyzed with a General Electric XR-D 5 X-ray diffractometer; nickel filtered, copper radiation was used. The samples were ground to below 200 mesh and mounted on a glass slide with a spatula; thus the mineral grains in the samples were relatively well oriented. A geologic map was prepared (Fig. 2); the units mapped were selected primarily on the basis of X-ray analyses and secondarily on their megascopic appearance. Thin sections and chemical analyses were studied.

Petrography

The metamorphosed sill was divided into four lithologic types:

(1) hornblende-oligoclase rock (2) chlorite-plagioclase rock, (3) chlorite-tremolite rock, and (4) chlorite-talc rock. The hornblende-oligoclase rock generally is darker in the lower portion of the body, and grades upward into lighter colored rock. Generally chlorite-tremolite rock near the base of the body grades upward into chlorite-talc rock near the center of the body; a chlorite-tremolite-talc phase is found between these two rocks. In the southern portion of the area chlorite-plagioclase rock, rather than chlorite-tremolite rock, was mapped between the hornblende-oligoclase rock and talcose rocks (Fig. 2).

The hornblende-oligoclase rock chemically is similar to gabbro (Table 2). In the lower portion of the body this rock principally consists of hornblende and oligoclase with minor amounts of quartz, actinolite, chlorite, epidote, ilmenite, and magnetite. The rock is phaneritic and dark green with grayish white flecks. The hornblende is pleochroic yellow to green and elongate; partially aligned laths are up to 10 mm long. Some hornblende has been altered to red iron oxides, chlorite, or epidote. Actinolite is found on the edges of a few hornblendes and as small (1-2 mm) rosettes of light green crystals. Small grains of oligoclase (1-2 mm in maximum dimension) are within some laths of hornblende. The cores of a few oligoclase grains have been epidotized and some of the epidote has been chloritized. Small amounts of quartz are associated intimately with plagioclase. Subhedral magnetite and ilmenite grains (average size about 0.5 mm) generally have red iron oxide rims that were produced by weathering. The hornblende-oligoclase rock in the upper portion of the sill is lighter colored than similar rock in the lower portion of the sill and contains major amounts of hornblende, actinolite, oligoclase, clinozoisite, and muscovite and minor amounts of chlorite, epidote, quartz, dolomite, ilmenite, and magnetite. The amphiboles and muscovites are found as large subhedral grains, up to 5 mm long. Small (less than 0.5 mm) anhedral grains of colorless clinozoisite and pale green epidote are associated intimately with oligoclase. Small (less than 0.1 mm) quartz grains are adjacent to oligoclase grains. Dolomite is found in veinlets (less than 0.5 mm thick). Opaque minerals are in smaller amounts in the lighter phase than in the darker phase of hornblende-oligoclase rock. The relatively high percentage of Al_2O_3 and CaO in the lighter phase (Table 2) probably is reflected by the abundance of clinozoisite.

Chlorite-plagioclase rock is dark green to black and generally aphanitic; commonly it has a shiny luster. Anhedral plagioclase (albite to oligoclase) is found interstitially among euhedral crystals of chlorite. Minor amounts of amphibole (hornblende and tremolite-actinolite), calcite, dolomite, and iron oxides are also found in this rock.

Chlorite-tremolite rock is phaneritic to aphanitic, gray to dark green, and strongly foliated; it contains minor anthophyllite, magnetite, ilmenite, and red iron oxides. The chlorite occurs as colorless

Table 2. Chemical Analyses*

	No. 1	No. 2	No. 3	No. 4	No. 5**	No. 6
SiO_2	45.8	47.0	45.0	42.1	43.0	42.8
Al_2O_3	16.3	21.0	15.4	10.7	11.3	6.28
Fe_2O_3	3.07	2.28	N.D.	0.83	0.90	2.74
FeO	10.7	4.07	15.8	9.40	9.34	5.87
TiO_2	2.24	0.54	1.08	0.37	0.41	0.26
CaO	10.5	13.2	3.43	6.53	3.02	2.94
MgO	4.71	5.93	9.04	22.1	23.7	28.0
Na_2O	2.42	1.91	1.43	0.05	0.05	0.01
K_2O	0.26	0.47	0.07	0.03	0.02	0.01
CO_2	0.17	N.D.	1.45	N.D.	N.D.	4.36
$H_2O(-)$	0.52	0.31	0.14	0.81	0.33	0.07
$H_2O(+)$	2.70	3.12	6.32	6.40	7.69	6.21

No. 1 - Hornblende-oligoclase rock (dark phase).
No. 2 - Hornblende-oligoclase rock (light phase).
No. 3 - Chlorite-plagioclase rock.
No. 4 - Chlorite-tremolite rock.
No. 5 - Chlorite-tremolite-talc phase.
No. 6 - Chlorite-talc rock.

*Analyses by M. Coller, Department of Geology, Indiana University, Bloomington, Indiana.

N.D. - Not-Detected

**This rock is quarried for use as soapstone.

to pale green, aligned to semi-aligned laths or as unaligned, anhedral material; both textural types of chlorite have a high magnesium to iron ratio, as determined by the method of Albee (1962). Tremolite occurs as colorless, rarely pale green laths; many laths are fractured and aligned, and a few have been altered to anthophyllite or to iron-rich chlorite.

Gray, aphanitic chlorite-talc rock consists principally of anhedral talc and magnesium-rich chlorite that have interlocking contacts. Red iron oxide streaks surround this partially aligned chlorite-talc mixture, and subhedral magnetite and ilmenite make up about 15 percent of this rock (as compared with about 10 percent in the chlorite-tremolite rock). The chlorite-tremolite-talc phase is mineralogically gradational between chlorite-tremolite rock and the chlorite-talc rock.

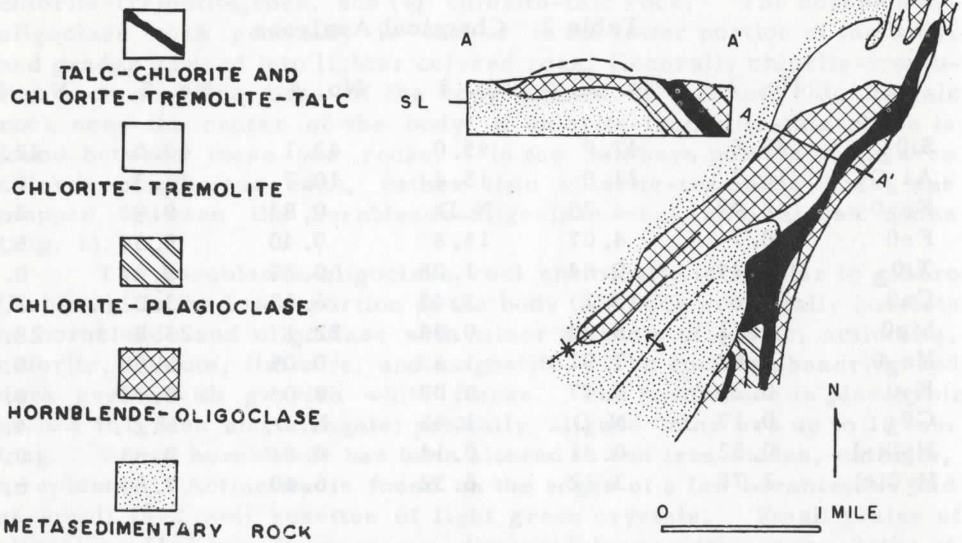

Figure 2. Geologic map and cross section of area studied. Cross section is twice scale of map.

REFERENCES CITED

Albee, A. L., 1962, Relationships between the mineral association, chemical composition, and physical properties of the chlorite series: Am. Mineralogist, v. 47, p. 851-870.

Bloomer, R. O., and Werner, H. S., 1955, Geology of the Blue Ridge in Central Virginia: Geol. Soc. America Bull. v. 66, p. 579-606.

Brown, W. R., 1958, Geology and Mineral Resources of the Lynchburg quadrangle: Virginia Division of Mineral Resources Bull. 74, 99 p.

Burfoot, J. D., 1930, The origin of the talc and soapstone deposits of Virginia: Econ. Geol., v. 25, p. 805-826.

Fairley, W. H., and Prostka, H. J., 1958, Soapstone Belt, Albermarle and Nelson Counties: open file geologic map, Virginia Division of Mineral Resources.

Hess, H. H., 1933, Hydrothermal metamorphism of an ultra-basic intrusive at Schuyler, Virginia: Am. Jour. Sci., v. 26, p. 377-408.

MARINE TERRACES: PRE-PLEISTOCENE?

by

William F. Tanner
Florida State University

ABSTRACT

Known marine terraces in the Southeastern States can be plotted on a chart having as ordinates time and elevation. An envelope, drawn through the highest points, indicates that sea level has been dropping since Oligocene time, at about 1 mm per 200-to-300 years, and that no marine terrace now standing more than about 10 m above present MSL, in the Southeastern States, can have been formed as late as Pleistocene time. This line provides tentative dates for high marine terraces in structurally stable areas.

* * *

Sea level, according to a widely-held concept, was more-or-less steady throughout Tertiary time and fluctuated greatly during the Quaternary. This fluctuation was made up of four large drops, each (except for the last) followed by an essentially complete recovery. An alternate history has included a long period of sea level stability, in Tertiary time, followed by four successively smaller fluctuations in the Quaternary. According to this popular scheme, the first major fluctuation (Nebraskan-Aftonian) was the largest (perhaps from + 100 meters to -135 m), and the latest fluctuation (Wisconsin-Recent) was the smallest.

The second of these versions was based on marine terraces: the higher terraces must be the older; inasmuch as there are four important high terraces they must represent Pliocene, Aftonian, Yarmouth and Sangamon times; if we could observe "low" terraces (i.e., below present sea level) we would find a similar but inverted relationship; and so on. The first version was, apparently, theoretical: an ice age, having four major glacial epochs, should produce four major drops in sea level.

There are, however, several other ways of getting at sea level history. One involves the plotting of dated marine deposits. When all of these are plotted, three "highest" elevations are pertinent. They are:

1. Hawthorn formation, early Miocene, at 80 m.
2. Duplin "marl", late Miocene, at 40 m.

3. Sangamon coral reef (Florida Keys), at 8 m.

The dates for these may be stated as about 25×10^6 yrs. B.P., about 15×10^6 yrs. B.P., and (based on radiochronology by J. K. Osmond) about 1.2×10^5 yrs. B.P. On ordinary coordinate paper, a straight line connects the three points. Many other points lie below this line: that is, they represent earlier or lower sea water positions. No known marine points lie above this line, in the Southeastern States.

Several interpretations are available. One is the possibility that the area hasn't really been stable, and therefore we are examining a "mixed" curve, having both structural and sea-level elements in it. An attempt is here made to reduce this possibility by staying away from structural elements such as the Cape Fear arch. Another is that erosion has removed all of the deposits which were originally above the line. This interpretation suggests strongly that more recent deposits were, somehow, more easily and efficiently removed than older materials; this does not seem likely. A third is that we have merely failed to find high-level marine sediments, or that such sediments contain no fossils and therefore cannot be interpreted and dated satisfactorily; this, although possible, is not attractive. A fourth is that most marine terrace material are relatively deep water deposits (i.e., up to 130 m. deep); much field evidence suggests the contrary. A fifth is that this line is really significant, after all.

Extrapolation of the line leads to interesting observations at both ends. Closer to us in time, it suggests that sea level rise may have, at the most, a few more meters to go, in the current deglaciation; that is, that not all of the ice (i.e., in Anarctica) melts in any one interglacial. At the other end, it suggests that sea level fall was initiated during Oligocene or perhaps Miocene time. If the four Pleistocene glacial epochs were roughly of the same intensity, the line also indicates that they took place on a slowly sliding base: that is, that each major sea level drop was greater than any preceding it, but also that each major rise failed to match the preceding recovery. From this it is an easy (but completely speculative) step to the notion of glacio-eustatic fluctuations in the Tertiary.

Direct reading of the line produces tentative dates for marine terraces in the Southeastern States. Elevations and possible dates can be listed as follows:

800-100 m: Oligocene.
40-80 m: Miocene; possibly Oligocene.
10-40 m: Pliocene; possibly Miocene or Oligocene.
0-10 m: Pleistocene; possibly earlier.

A different listing might look like this:

Sunderland-Okefenokee: Miocene (possibly Oligocene).
Surry-Wicomico: early Pliocene (possibly older).
Penholoway: middle Pliocene (possibly older).
Pamlico: Pleistocene (possibly older).

The slope of the line can be expressed as, roughly, 1 mm of

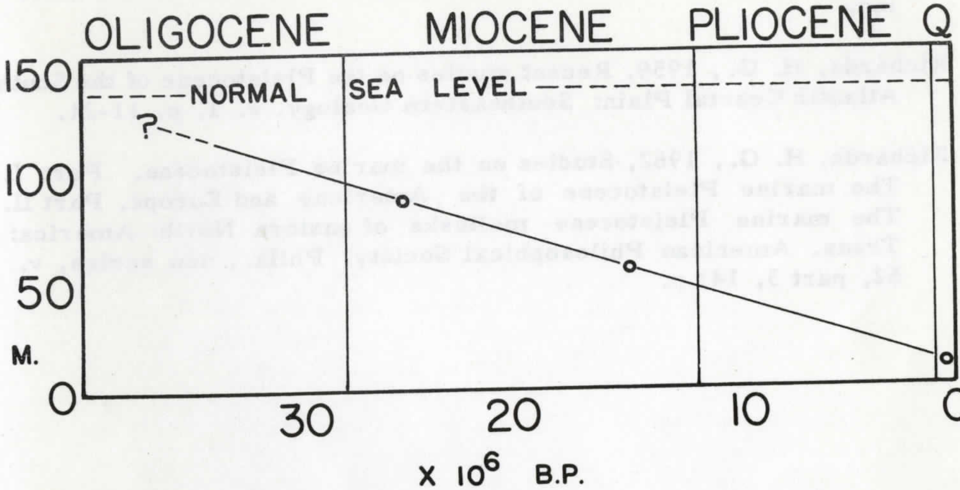

Figure 1. Sea-level-fall curve, drawn as a straight line (hence maximum generalization) through the three highest known points for the Southeastern States.

drop in some few hundreds of years (i.e., 200 or 300), since about mid-Oligocene time. However, once the straight line has been adopted for discussion purposes, it must not be thought of as a correct and detailed curve. Even if it were precise, in the limiting sense (which it isn't), it would fail to define those fluctuations which fall completely below the line. Hence, in the list given above, Pamlico terrace materials are dated as "Pleistocene (possibly older)." But the essence of the idea presented here is that, with the available information, we can date, for instance, the Sunderland-Okefenokee terrace only as Oligocene or Miocene, and <u>not</u> as later. If we wish to assign this level a Pliocene or Pleistocene date, we must do so without field evidence.

The conclusion, drawn tentatively from the present line of reasoning, is that sea level has dropped, in a systematic way, since roughly middle Oligocene time, and that Pleistocene fluctuations, although sharp, have not accounted for any marine features (in the Southeastern States) more than perhaps 10 m above present sea level.

Although Richards (1959) at one time assigned both Pamlico and a 90- foot terrace to the Sangamon (but recognized no other interglacial terraces), he has subsequently (1962) indicated that levels higher than about 15 m are either alluvial, colluvial, or pre-Pleistocene. Alt and Brooks (1964) reached similar conclusions, as did Richard Russell (personal communication).

REFERENCES

Alt, D., and H. K. Brooks, 1964, Evolution of the landscape of

Florida: Program, Geological Society of America, annual meeting.

Richards, H. G., 1959, Recent studies on the Pleistocene of the South Atlantic Coastal Plain: Southeastern Geology, v. 1, p. 11-21.

Richards, H. G., 1962, Studies on the marine Pleistocene. Part I. The marine Pleistocene of the Americas and Europe. Part II. The marine Pleistocene mollusks of eastern North America: Trans. American Philosophical Society, Phila., new series, v. 52, part 3, 141 p.